

Figure 50. Nitrate drum removed from monolith with grout adhering to the surface of the drum.



Figure 51. Drum with lid removed showing solid grouted interior with “J” seal visible about 12.7 cm (5 in.) into the top.



Figure 52. Puncture of drum by the drill steel (left-hand side of drum), showing the cylindrical shape of the drill steel.

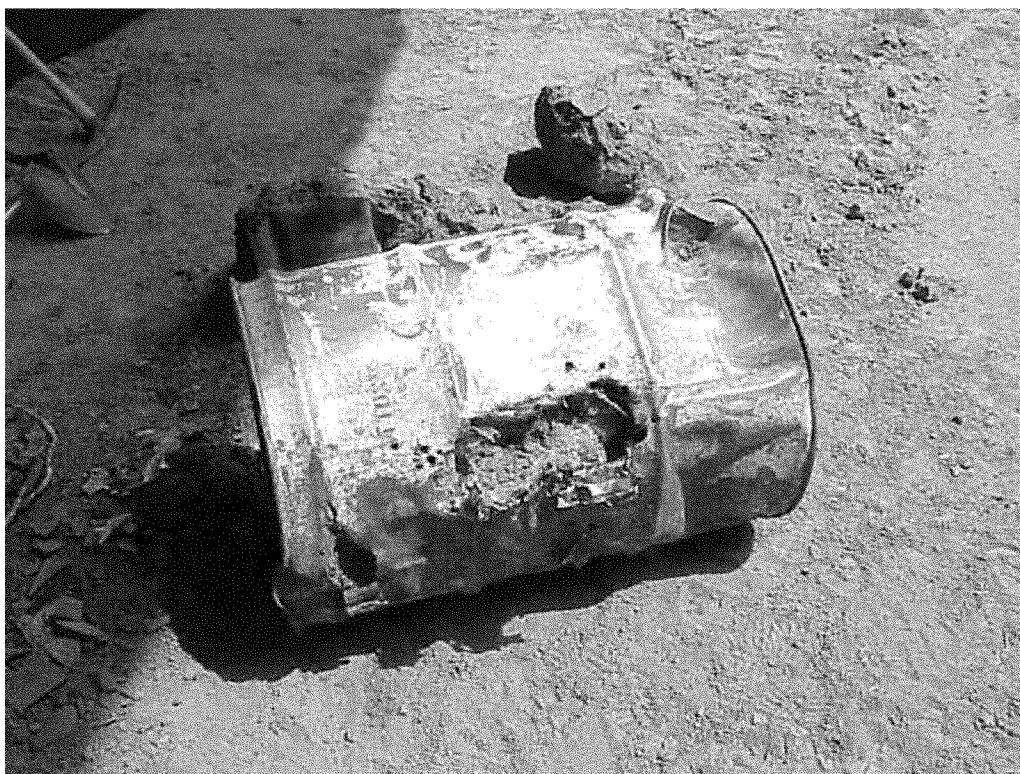


Figure 53. Hole in metal side of drum showing grouted nitrate salts in middle and neat grout on ends.

Accounting for a 5% weighing error, the most that could have been delivered to the drum would be the error ($0.05 \times 450 \text{ lbm} = 22.5 \text{ lbm}$) plus the 69 lbm or 41.5 kg (91.5 lbm). At 41.5 kg (91.5 lbm) there could have been at a maximum a total of 23L (6.1 gal) delivered to the drum which is much lower than the theoretical amount of 34L (9 gal) delivered based on the 22.8 cm (9 in.) of travel of the drill stem. With a 0.61m (2 ft) diameter in the drum there is approximately 7.2L (1.9 gal) of volume per inch of drum height. Therefore, if 23L (6.1 gal) had been injected into the drum, a linear total of 8.1 cm (3.2 in.) of empty drum length could have been completely filled. This then supports the idea that the grouting action only filled the peripheral edges where there was a large void. If the drum had been struck straight on by the drill stem and further that there was a full 60.9 cm (24 in.) of travel then the amount of grout delivered into the drum would have roughly tripled (as much as 102 L [27 gal]). This action would have certainly filled all voids in the drum and most likely even overflowed a mixture of nitrate salts and grout into voids surrounding the drum.

As the excavation proceeded, two more recognizable waste forms were photographed including a grouted drum containing combustible material and material from the 1.2 x 1.2 x 2.4-m (4 x 4 x 8-ft) box. Figure 54 shows the grouted combustible drum, and Figure 55 shows the grouted boxed material.

The fact that these two simulated waste containers had grout means that the terbium tracer in the containers could have spread to the top surface of the thrust block and to other positions within the contamination control system.

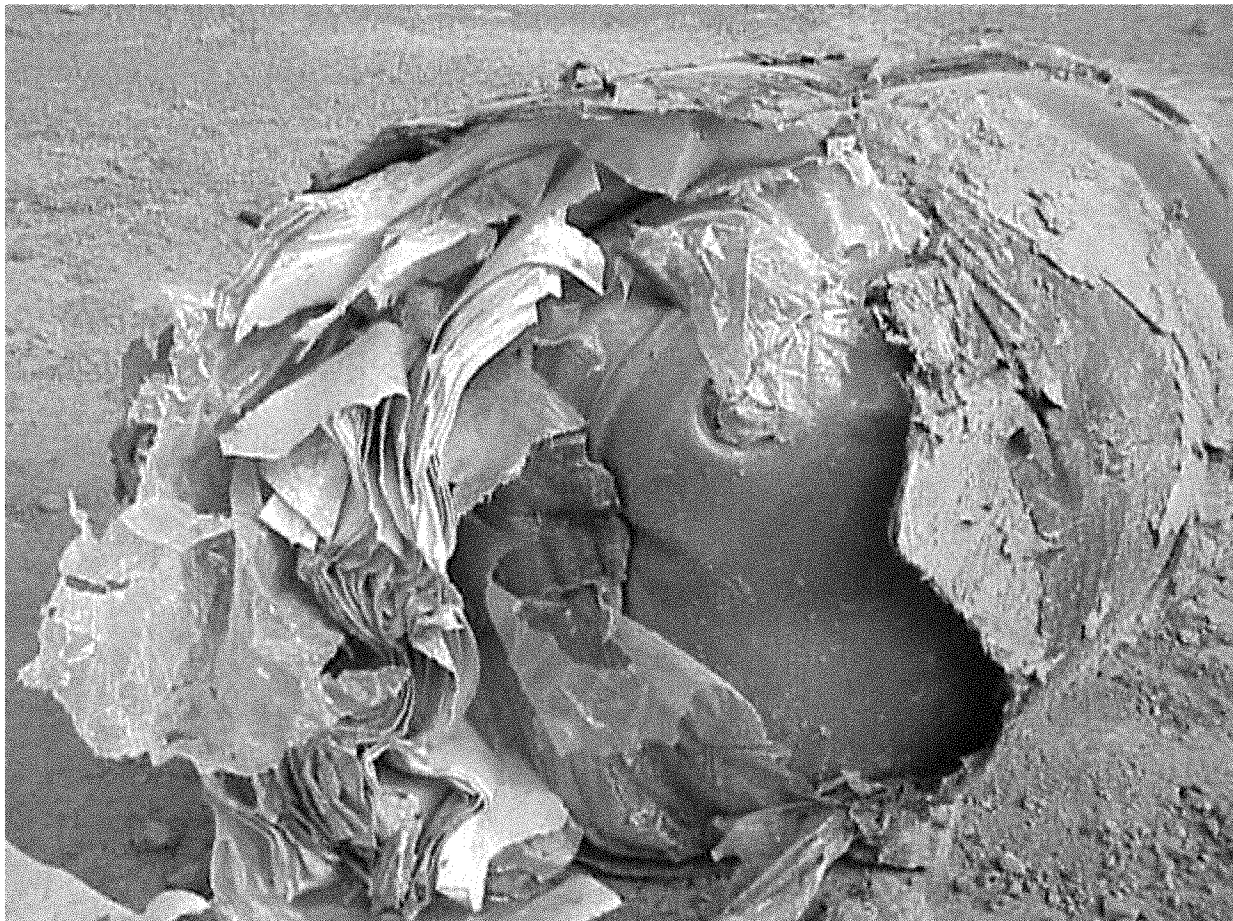


Figure 54. Grouted drum containing combustibles.



Figure 55. Grout in contents of $1.2 \times 1.2 \times 2.4$ -m ($4 \times 4 \times 8$ -ft) box.

6. LESSONS LEARNED

During the limited field demonstration, several lessons were learned. Some of the lessons were related to operations of the system, and others are related to the accident due to the catastrophic failure of a high-pressure fitting.

6.1 General Lessons

Using the thrust block concept requires a complete new design of a vacuum relief system within the drill string. The new design should allow complete automatic draining of the drill string of neat grout prior to moving the drill string to a new hole. Following grouting, simply letting the drill string drain of fluid through the nozzle was not sufficient in that the vacuum created by partially draining the drill string held up fluid. This fluid, once jostled upon moving the system, caused fluid to drain into the bag formed by using duct-tape to tie off the plastic sleeves in the thrust block. In one occurrence, the bag like container formed by the taping process was filled with several liters of neat grout and the bag fell off onto the top surface of the thrust block potentially spilling contaminants. The solution is a high-pressure vacuum relief valve located in the high pressure delivery line. This valve could be remotely operated only at low pressures to open the system allowing complete draining of the drill string.

When the plastic sleeve is installed onto the stinger of the drill string, the process could be simplified by attaching the two bags as if they were one bag rather than attach each bag individually. This action would save operations time in that placing the inner first bag on the stinger is difficult when working within the confines of the second outer bag. The plastic bag material should be a very soft pliable material that doesn't easily stick to metal surfaces and to other similar plastic surfaces.

Prior to restart each day, residual cured grout and other debris should be removed from the drill string by the grouting subcontractor by repositioning all drill strings with shrouds in the vertical position with the sub assembly removed. Water should be flowed through the entire system using the JET-5 pump in the lowest pressure mode while applying rotopercussion to the system to remove all residual cured grout product. This can be done outside the test area at the mouth of the tent. In an actual hot application, this process could be done in a glovebox environment.

As a refinement of the existing drilling sequence, the nozzles should be positioned away from the cameras under the thrust block with a no flow situation, and a trickle flow of grout started with a combination of the low pressure feed system and triplex pump as needed. Only after the trickle flow starts, the nozzle should be placed into the gravel layer and the flow gradually increased as the system is drilled into the pit. In this manner, the cameras can be protected and plugging can be reduced.

It is recommended that the grout plant be located adjacent to the grouting operation to avoid wastage of grout. The output of the plant should be double screened and the supply hopper to the high pressure grouting pumps should be double screened.

If operations are to be performed in the winter months, it is recommended to provide the outside pump personnel and equipment with a temporary weather structure. This would make it easier to avoid ice formation in pumping equipment and improve radio communications between outside pump operators and inside drilling operators. When the air temperature is -1°C (30°F) with a 48-km (30-mph) wind, personal protective gear makes it difficult to use radios.

In an actual hot application, there should be a glovebox adjacent to the drilling area into which the drill string can be inserted. Within the glovebox, the drill string can be extended past the stinger and allow operation access to the nozzles for nozzle unplugging. The bag formed by twisting off the thrust block

plastic sleeve would be left in the glovebox (it would automatically fall off into the glovebox when the drill string was extended past the stinger) and a new “bag” of plastic would be placed on the stinger as the drill string comes out of the glovebox. In this manner, changeout of the entire drill-string shroud assembly would be avoided for something as common as a plugged nozzle.

6.2 Lessons from the Accident

The grouting subcontractor should install a high pressure relief valve and a redundant pressure relief plug system which would allow emergency bleeding of the system. The primary system would be a valve and the secondary system would be a simple plug located in an easily and safely accessed area. This emergency plug should allow safe easy access for wrenches and needed hammers in the event of a system pressurized by nozzle plugging. Once the plug has been forced open in an emergency, it should be replaced with a new plug/and or fitting. In addition, as part of the emergency procedure, the relief system should be cleaned or replaced if used to ensure proper operation.

The grouting subcontractor should check the setting on the automatic shut off feedback switch periodically. This will require a pressurization procedure using water and may require special plumbing to accomplish the testing. The incident at the Cold Test Pit suggests rapid uncontrolled overpressurization by the triplex pump not shown on the gauges. If a nozzle plugs, the operator needs automatic backup help independent of the gauges.

The grouting contractor should use only pressure gauges that operate smoothly at all pressures. It is speculated that the gauge used during the field test sticks at lower pressures and unsticks when the pressure gets higher. For instance the gauge can read 20 bar when it is really at 500 bar about to go to 1,000 bar with a few more strokes of the triplex pump. If not already used, a read-out of the Jean Lutz system may be implemented. It is recommended that there be two gauges, one that is used during low-pressure operations and another that is used during high pressure operations. It may be required that the low-pressure gauge must be valved in to operate at low pressures and valved out when operating at high pressures.

The grouting contractor should use only rated equipment and fittings such as valves, hoses, and tie-downs. The tie-downs and fitting documentation should accompany the fittings for an operating pressure expected of 400 bar (6,000 psi) and safety limits at the design pressure of the pump.

The idea of using 3-mm nozzles for U.S. Grout and GMENT-12 grout should be reevaluated with the new pressure gauges. It is possible that during the nozzle optimization tests at the subcontractor Richland site the pressure gauge showed a pressure of 200 bar (3,000 psi) when in fact the system was pumping at a much higher pressure. Evidence of this was various obvious overpressurization events that occurred when performing the initial nozzle optimization tests performed prior to the implementability testing. What is needed is another separate effects test in soil at the INEEL Cold Test Pit involving improved pressure control and both the 2.4 and the 3-mm nozzles. If the 3-mm nozzle could be used instead of the 2.4-mm nozzle, the potential for nozzle plugging would be greatly reduced. This basically could be accomplished in a 2-day test involving grouting at the end of the week and digging up the columns on Monday following a weekend cure. Using the improved pressure measurement systems, If the system cannot be pressurized to 400 bar with the 3.0-mm nozzles, then, there would be no need to dig up the columns. However, if the system can be pressurized to 400 bar with the 3-mm nozzles, a series of three columns 4 ft high need to be created only varied by the step time. The suggested step times are: 3s, 4s, and 5s.

Because of possible mechanical loads on the Jean Lutz system during the accident, this system should be recalibrated using a barrel filling technique before operations resume.

A blast shield around the outlet to the high-pressure pump is recommended to deflect any future blowout due to catastrophic failure of any fittings in the vicinity of the Jean Lutz and High pressure pump. The system should be attached to protect the tent, the driver, the grout control man and the pump operator. The shield could be designed for easy-on/off attachment.

Although there were many safety issues that required addressing following the accident, the overall technology was working. The main problems involved the long delays due to nozzle plugging. In fact, nozzle plugging could be considered one of the root-causes of the accident. Some slight modifications to the procedures would greatly eliminate the nozzle plugging that was observed including: 1) use of the 3 m nozzles, 2) complete dynamic clean-out of the Applied Geotechnical Engineering and Construction system, 3) double screening of material at the batch plant, and 4) observing a positive trickle flow prior to nozzle insertion into the gravel using the cameras.